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A Raspberry in Sub-Saharan Africa?

Chances and Challenges of Raspberry Pi and Sensor Networking in Humanitarian Logistics

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Abstract

This paper addresses the chances and challenges of humanitarian logistics in Sub-Saharan Africa with a special view on the application of single-board computers – such as the Raspberry Pi – in combination with sensor networking. In this connection the paper deals with the following questions: Which special circumstances in and challenges for Sub-Saharan Africa need to be considered? How can humanitarian logistics contribute to enhance the supply of people in need with food and medicines? Are Raspberry Pi or other single-board computers and their integration into sensor networks adequate solutions for humanitarian logistics and the supply of food and medicines in Sub-Saharan Africa?

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Keywords: Humanitarian Logistics; Raspberry Pi; Sensor Networking; Africa, Cold Chain; Single-Board Computer

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1. Introduction

For Sub-Saharan Africa can be stated that droughts and hunger occur regularly and that life expectancy is comparatively low. Many challenges have to be addressed to overcome the existing situation, e. g. the supply with food and medicines must be enhanced and there are necessities to improve the infrastructural situation as well as education and political conditions. When addressing these challenges special circumstances in African countries such as heat, humidity, power outages and others have to be taken into account.

This paper addresses the chances and challenges of humanitarian logistics in Sub-Saharan Africa with a special view on the application of single-board computers – such as the Raspberry Pi – in combination with sensor networking. In this connection the paper deals with the following questions: Which special circumstances in and challenges for Sub-Saharan Africa need to be considered? How can humanitarian logistics and supply chain management contribute to enhance the supply of people in need with food and medicines? Are Raspberry Pi or other single-board computers and their integration into sensor networks adequate solutions for humanitarian logistics and the supply of food and medicines in Sub-Saharan Africa?

Answers to these questions – and in addition still open research questions – will be given in this paper on basis of literature and statistics analysis, former experiences in humanitarian logistics research, first on-location inspections in Africa and tests with the Raspberry Pi and surrounding networks.

One central objective is to identify a fast and low cost temperature control system (estimated overall costs of the whole system max. US$ 350) for humanitarian logistics in Sub-Saharan Africa, which is easy to implement, to use and to maintain and which works effectively (e.g. fast and reliable).

2. Challenges for Sub-Saharan Africa

Winner of the peace Nobel Price Wangari Maathai describes in her book “The Challenge of Africa” [1] in a traceable way a traditional African stool, which is comprised of a seat and three legs: Within the picture of a three leg stool

- the first leg represents democratic space, where rights are respected,
- the second leg symbolizes the sustainable and fair management of natural resources, and
- the third leg stands for the culture of peace in form of fairness, respect, compassion, forgiveness, recompense, and justice.

The three legs of the stool support the seat, which represents the milieu in which development can take place. In Africa today, a number of countries are trying to balance on two or less of the stool’s three legs. “It is essential to recognize when one or more of the three pillars is absent, and accept that, no matter how many funds are provided, in a country that is balancing on two, one or no legs, the money may not only be wasted or have only a temporary effect, but may even contribute to the continuing instability of that society [1, p.58].” Maathai describes several examples, especially from Sub-Saharan Africa and necessary measures to overcome such situations. This is a wide view on the macro-level of the challenges of Sub-Saharan Africa challenges. We should bear them in mind when dealing with humanitarian logistics in Africa.

Going more into detail with view to consequences of instability and other special circumstances in Sub-Saharan Africa, several statistics describe the actual situation these countries and their people face. The World Health Statistics 2014 published by the World Health Organization (WHO) is one of the central statistics with view to health, nutrition, and other central information with relevance for humanitarian aid and humanitarian logistics [2]. This report and statistics also address the eight UN Millennium Development Goals (MDG) as they have been defined in the year 2000 and as they will be met until the year 2015 [3]. But with a special view to Africa and Sub-Saharan Africa several goals will not be fulfilled until 2015, e. g. the reduction of poverty, malnutrition, and hunger in Africa. In addition there are still enormous differences between the worldwide regions. For example the risk of a child dying before the fifth birthday is still highest in the WHO African Region (95 per 1000 live births) – eight times higher than that in the WHO European Region (12 per 1000 live births, see [3] and [4]). Sub-Saharan Africa faces the highest rate of worldwide deaths regarding vaccine-preventable diseases. More than 2.4 million children are killed annually and millions more get permanently impaired due to missing health treatments [5].

Table 1. Central findings from the WHO 2014 statistics [2] with reference to UN Millennium Development Goals [3].

	African Region	**European Region**	**Regions of America**	**Global**
Life expectancy 2012 at birth ([2], p. 68), (male / female)	58 (m 56/ f 59)	76 (m 72/ f 80)	76 (m 74/ f 79)	70 (m 68/ f 73)
Infant mortality rate 2012, probability of dying by age 1 (by age 5) per 1000 live births ([2], p. 69) → *MDG 4 "Reduce child mortality"*	age 1: 63 age 5: 95	age 1: 10 age 5: 12	age 1: 13 age 5: 15	age 1: 35 age 5: 48
Maternal mortality ratio per 100000 live births 2013 ([2], p. 90) → *MDG 5 "Improve maternal health"*	500	17	68	210
Cause specific mortality rate per 100 000 population 2012 ([2], p. 90) → *MDG 6 "Combat HIV/AIDS, Malaria and other diseases"*				
- HIV/AIDS	377	20	20	56
- Malaria	63	0	0.1	11
- Tuberculosis	26	4	2	13
Numbers of reported cases, here **Malaria** 2012 ([2], p. 102)	77 079 733	27 030	143	89 194 435
Total expenditure on health ([2], pp. 150/151)				
- as % of GDP 2011	6.2	9.0	14.1	9.1
- per capita (US $)	95	2 370	3 482	1 007
Underweight children aged < 5 years, in % 2006-2012 ([2], p. 126) → *MDG 1 "Eradicate extreme poverty / hunger"*	24.6	1.5	2	15.1
Population living on less than one $ a day, in % 2006-2012 ([2], p. 175) → *MDG 1 "Eradicate extreme poverty / hunger"*	51.5	0	5.1	21.5
Population using improved in % 2012 ([2], p. 126)				
- **drinking water**	66	98	96	90
- **sanitation** → *MDG 7 "Ensure environmental sustainability"*	33	93	88	64
Primary school enrolment rate, in % 2006-2012 male and female ([2], p. 175) → *MDG 2 "Achieve universal primary education"*	m 81 f 77	m 98 f 97	m 95 f 96	m 92 f 90
Cellular phone subscribing per 100 population 2006-2012 ([2], p. 175) → *MDG 8 "Global partnership for development"*	61	129	104	89
Living in urban areas, in % 2012 ([2], p. 176)	39	71	80	53

Table 1 summarizes important findings from the World Health Statistics 2014 [2] with a comparison between Africa, Europe, America and the global situation. The data represent the actual situation within the sectors health, nutrition, sanitation, education, technic and others and refer to the eight UN MDGs [3]. Even if table 1 shows summarized data for the whole continent, the information for each African country is available within the report. If necessary, the information can be extracted for Sub-Saharan Africa. Lower life expectancy, higher mortality and malnutrition rates, lower educational level, less people living in urban areas – all these are situations for African countries which become even more apparent for the regions of Sub-Saharan Africa.

Other important statistics for humanitarian logistics describe special situations in the aftermaths of disasters which occur either permanent (e.g. droughts) or acute (e.g. volcanic eruption or flood). Findings from the Annual Disaster Statistical Review [6] show that most disasters in Africa are hydrological, climatological and meteorological disasters. Droughts are the most frequent kind of disasters in Sub-Saharan Africa. Experiences from the past show that the negative impacts on the population are particularly high in countries with situations of political instability, crisis or war. In comparison to more industrialized continents like Europe and Northern America the impacts in Africa are significant higher numbers of deaths and victims in case of a disaster and significant lower economic damages (see table 2).

Table 2. Natural disasters and impacts, annual average 2003-2012 [6].

	Africa	**Europe**	**North-America**
Occurrence (amount)	72	55	92
Victims (amount in million)	30	0.6	9
Economic damage (US $ billion)	1.24	13.11	66.16

When dealing with humanitarian logistics and technical solutions such as the Raspberry Pi it is essential to know the situation, challenges and special circumstances in African countries. Information about the dimension of health and malnutrition, rate of population living in urban areas, the spread of mobile phones and other technics are important information for humanitarian logistics and the supply of food and medicines.

3. Humanitarian Logistics – Definition, goals, chances and challenges for Africa

Humanitarian logistics is defined “as the process of planning, implementing and controlling the efficient, (cost-) effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people. The function encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking and tracing, and customs clearance ([7], p. 2).” This definition is adopted by several authors and organizations (e.g. [4]).

The aims and goals are part of the definition: “efficient, “effective” and “for the purpose of alleviating the suffering of vulnerable people”. For most humanitarian organizations a high logistics service has a higher priority than the logistics costs. With a good or even optimal logistics service the supply is quick, save and reliable. If the right goods (e.g. food and medicines) are received by the right people (the most affected people and people in need), at the right place, at the right time (as fast as necessary) and with the right quality (e.g. high quality of food items or medicine even in situations of extreme weather), then humanitarian logistics can contribute to alleviate the suffering of vulnerable people. Often it even can save lives. The “right” logistics costs (e. g. for infrastructure, human resources, food and non-food items) are part of the aims, as well. If humanitarian organizations lower the logistics costs, they can use the budget for the core tasks of humanitarian aid. With this, the aim for humanitarian logistics can be defined as maximizing logistics services under the restriction of given logistics costs (e.g. [4]). The use of the Raspberry Pi or alternative solutions and sensor networking for humanitarian logisticians must be geared to these aims.

In 2014 the World Bank published the new Logistics Performance Index (LPI) which compares the logistics performance of 160 countries in the world regarding six components: customs, infrastructure, ease of arranging shipments, quality of logistics services, tracking and tracing and timeliness [8]. African countries regularly perform weakly. One of the problems most countries in Sub-Saharan Africa do have is the lack of connectivity within supply chains and global networks. This phenomenon was also detected by Kessler [9] – he states that most of the IT systems used in African supply chains are incompatible with each other, thus, many organizations and logistics providers do not use IT systems at all, but paper-based documentation. Visibility, transparency and controllability of supply chains are not possible within this situation. This leads to congestions of sensitive hubs (like ports and central distribution hubs), long leading-times and high costs of operation.

Reasons for that can be found on a wider macro-level in the financial and political situation of many African countries, the above mentioned picture of “stools with less than three legs” and the consequences. Transporting, storing and distributing products within African developing countries are often inefficient and ineffective, as transport networks, means of transportation, appropriate warehouses with appropriate equipment, IT-infrastructure and well-educated personnel are missing. Corruption, high bureaucracy, unstable, extreme weather conditions and daily power failures due to a fragile electricity network aggravate the situation. Especially decentralized warehouses in rural areas are mostly built in a simplistic way, e.g. lack of isolation (see [1], [9], [10], [11], [12]). Figure 1 shows on the left side an example of a central warehouse in Cameroon. As it can be seen, the roof is not well isolated and the walls show big water stains. The boxes for warehousing and transport on the right show lack of isolation.

Fig. 1. (a) Central warehouse in Cameroon [12]; (b) Example for containers, picture own source from 2013.

Figure 2 shows examples of an insight of goods in transit in Tanzania with a view inside the port of Dar Es Salaam. The pictures give impressions of weather conditions – heat and humidity – with effects on the road conditions and the conditions of rusty and not fully isolated containers. In rural areas the situation becomes even worse.

Fig. 2. Impressions from African seaports and road conditions, pictures own source from 2013.

4. The project sensor networking and Raspberry Pi in humanitarian logistics

4.1. Challenges of cold chains

The Raspberry Pi and sensor networking project aims to meet the above mentioned special challenges in Sub-Saharan Africa, with a special view on the supply of medicines and food within cold chains. In order to ensure potency and safety, certain pharmaceutical products (e.g. vaccines) need to be kept cool, in general between 2-8°C. Keeping them too cold can damage them as much as keeping them too warm. Studies have detected that 14-35% of refrigerators have exposed vaccines to freezing temperatures [13]. Only 29% out of 70 countries manage to keep their temperature controls at the minimum recommended standards [5] and the waste of vaccines in developing countries amounts to 151 million vaccines due to improper refrigerating [14]. The situation in the supply of food can be compared with the distribution of medicines in most of the above mentioned aspects, especially in "cold chains" where temperature is central for the quality and resistance of the product. Over 350 million tons of food are wasted or spoilt during the post-harvest phase (handling and storage) and the financial damage of food losses and waste amounts to US$ 310 billion in developing countries. A big amount of this loss occurs due to poor handling regarding the wrong temperature and humidity factors ([15] and [16]).

4.2. Objective, basic information, and test environment

To meet the above mentioned challenges, the objective of the Raspberry Pi and sensor networking project is to identify a fast and low cost temperature control system (estimated overall costs of the whole system max. US$ 350) for humanitarian logistics in Sub-Saharan Africa, which is easy to implement, to use and to maintain and which works effectively (e.g. fast and reliable).

A sensor network transforms analog data from the physical world to digital data which can be processed, stored and acted upon. Network-aware devices are connected and communicate with each other to support human-beings ([17] and [18]). In Figure 3 the different modules of a sensor network and their interaction are shown.

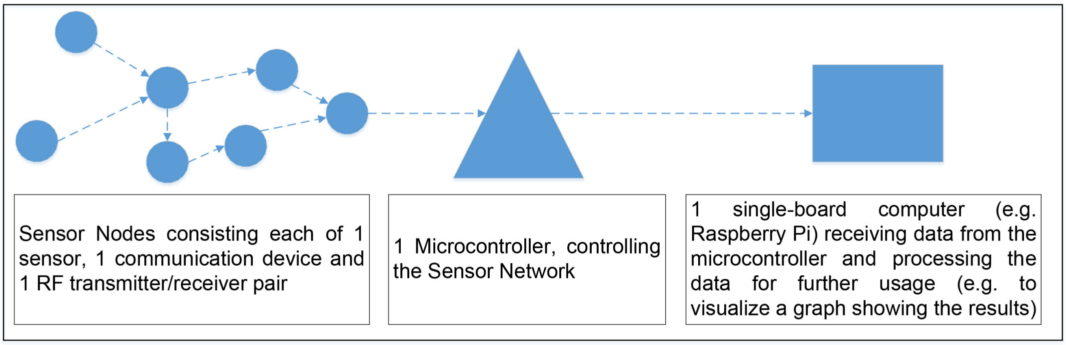

Fig. 3. Example of a Sensor Network [21].

All sensor networks have the same basic structure: Sensors measure phenomena of the physical world like temperature, humidity, light, gases, water vapor, etc. and translate them into signals (analog or digital) that can be measured and analyzed. Sensor nodes are composed of one or more sensors and a communication device to transmit the data. Depending on the type of sensor node, they can store (Basic Sensor Node) or only pass data in the network (Data Nodes). Usually, wireless sensor nodes are used which send their data to the next sensor being closest until the data reaches the microcontroller being connected to the sensor network. As they are working one-way, always two modules are necessary – a transmitter and a receiver ([17] and [19]). In order to control and monitor the sensor nodes, a microcontroller is necessary. A microcontroller is a small computer on a single integrated chip consisting of a processor, memory and programmable input/output circuitry. They are used in embedded systems where small software programs control and monitor hardware devices. One popular system is the Arduino. It is a physical open-source computing platform, based on a simple microcontroller and a development environment for writing software for the board ([19] and [20]). As soon as the sensor network works data can be sent, tracked and stored on a connected or embedded database, but not be processed. In order to convert data to another format, to incorporate it in an application or to print it as a hard copy, more computational power is necessary.

One option for a small, low-cost computer with sufficient processing power is the Raspberry Pi. This single-board computer of the size of a credit-card was developed in 2012 by the British Raspberry Pi Foundation and costs between US$ 25 (Model A) and US$ 35 (Model B and B+). It has a Broadcom BCM2835 system on a chip (SoC) including a 700 MHz-ARM11-processor and a HDMI interface (Raspberry Pi Foundation 2014). The models differ in RAM (Model A: 256 MB; Model B and B+: 512 MB) and interfaces (Model A: 1 USB 2.0 port and 17 GPIO-Pins; Model B: 2 USB 2.0 ports, Ethernet port and 17 GPIO-Pins; Model B+: 4 USB 2.0 ports, Ethernet port and 26 GPIO-Pins) as well as in the type of data storage (Model A and B: SD Card; Model B+: microSD Card) for booting and persistent storage. Several open-source operating systems have been developed, e. g. Raspbian, which is a Debian-based Linux-Distribution. To fully use the Raspberry Pi for sensor networks, a HDMI monitor, a USB mouse and keyboard as well as a 5V power supply need to be plugged in ([19], [22]).

For the test environment a Raspberry Pi Model B with the operating system “Raspbian” was used. This system is based on Debian and is optimized for Raspberry Pi hardware. The sensor which tracks temperature and humidity is called HMS 100TF and is generally used for home automation. The sensor can track temperature from -30°C to +70°C and humidity with a resolution of 1% and precision of ±8%. Its maximum range is 100 meters (free field) and the sensor transmits the measurements on a frequency of 868MHz. It has a microcontroller already included; the use of Arduino is not necessary.

To receive the radio frequency signals from the HMS sensor at the Raspberry Pi, additional hardware is required. Thus, a CUL (CC1101 USB Lite) V3.4 by busware is attached to the Pi via a USB 2.0 port. The CUL is a RF device in form factor of a USB dongle with external antenna and is necessary to receive and send 868MHz RF signals. It works with “culfw”, a firmware which implements RF protocols (especially FS20/FHT/S300/EM/HMS) on the CUL. The data is then made usable by fhem – a server for house automation – which runs on the single-board computer and coordinates all tasks [23]. The test environment can be seen in Figure 4.

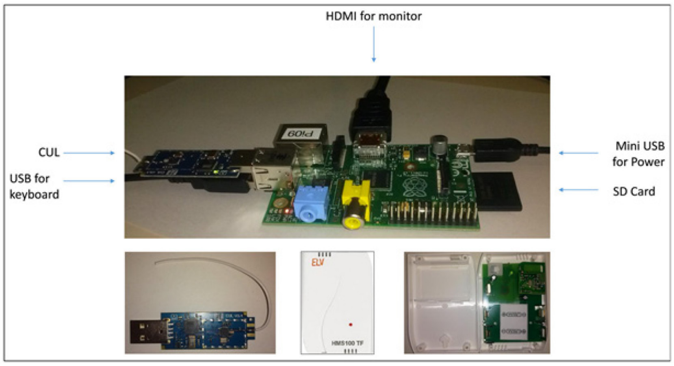

Fig. 4. Test environment [21].

4.3. First results and findings

Figure 5 shows a graph with first results from the measurements – on base of the GPL'd perl server “Fhem”. GPL stands for General Public License and is a widely used free software license, perl is the programming language. The test measurement was conducted for about 10 hours in a fridge: the red graph shows the temperature in the fridge, the blue one represents humidity, the increase of temperature and humidity happened due to opening the door. The graph represents possible measurements in real humanitarian logistics environments in Sub-Saharan Africa.

In order to verify, if such systems meet the introduced challenges and goals, different factors have to be considered, especially power requirements, alarm system, personnel requirements and overall costs [21].

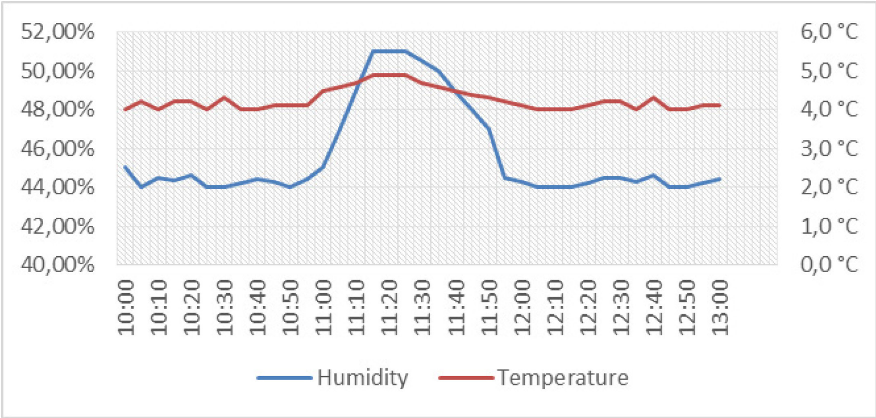

Fig. 5. Results from test measurement of sensor network, own graph [21].

Power requirements: In the testing phase power packs were connected to the Raspberry Pi and the sensor network; such systems can work autonomously. A single-board computer like the Pi needs approx. 500-700 mA at a voltage of 5 V (for model A, Model B+ needs less mA at a voltage of 5 V), USB devices like the USB-Dongle, mouse and keyboard raise the necessary power consumption and additional system parts usually require a higher usage of energy. A power bank needs at least a capacity of 10,000 mAh in order to supply the IT-infrastructure with sufficient power for one day (due to own measurements). As the energy failure usually happens without warning, the power pack needs to be connected to the system continuously to avoid system failures. Such power packs have a limited operating life and need to be changed regularly (with effects on the costs). Alternatives could be e.g. self-sufficient systems with renewable energy. Alternatives to the test environment should be tested regarding power and other requirements.

Alarm system: Concerning the alarm system a light bulb was used for the testing phase. It is switched off by the Raspberry Pi if the temperature is within the present temperature zone and is switched on, if the temperature leaves this zone. A sound-system could be integrated additionally. Furthermore the alarm system could be connected to GSM (Global System for Mobile Communication) sending SMS (Short Message Service) in case the present temperature zone is left – but additional costs must be calculated.

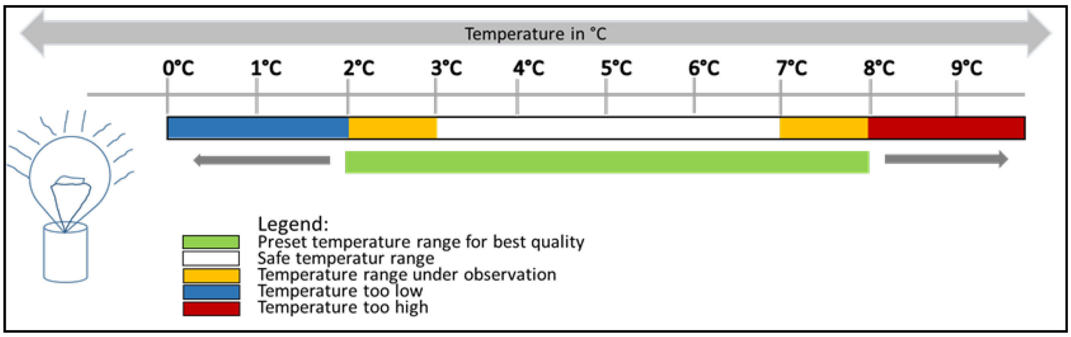

Fig. 6. Alarm system depending on measures, own figure [21].

Personnel requirements: The Raspberry Pi and other single-board computers usually come without any installed programs, what increases the necessary time to install a sensor network. Therefore, it is beneficial to have a person with IT affinity on-site as well as internet connectivity close-by (access to online-manuals and tutorials). If somebody is familiar with programming the field of use of the single-board computer can be extended depending on the needs of the warehouse management. If the system works, the actual usage of the monitoring system is easy – even for people with little educational background, as the alarm system as well as the graph provide immediate and understandable information about the state of the goods referring to temperature and humidity.

Overall costs: The Raspberry Pi costs between US$ 25 and US$ 35, but to make it fully usable, further components are necessary. Even if the test environment was built up with a model B, a Raspberry Pi model B+ is more efficient and effective. The model B+ needs less power and possesses 4 USB connections.

- US$ 35 calculated for the single-board computer. In addition:
- monitor (US$ 100),
- CUL CC1101 radio receiver (US$ 70),
- sensor for temperature and humidity HMS 100 TF (US$ 30),
- power-pack (US$ 30),
- HDMI cable (US$ 10),
- USB keyboard (US$ 10),
- SD card (US$ 10),
- further components (less than US$ 10 each): a case box to protect the Pi (US$ 5), a Wi-Fi USB Stick (US$ 5), others (together approx. US$ 15) such as USB mouse / adapter / connectors / batteries,
- eventually a GSM shield for an alarm system via SMS (US$ 70) and eventually an Arduino (approx. US$ 50 depending on the type – not necessary in the test environment due to choice of sensor).

All needed parts added up create costs of approx. US$ 320 (US$ 440 including Arduino and GSM shield). This amount of costs correlates to market prices in the EU for new components. If African countries succeed in negotiating special prices from vendors and retailers, quantity discounts in case of higher amounts or second hand products, the overall costs could possibly be reduced. In addition, shipping costs and customs have to be taken into account if some of the products are not available in African countries and personnel costs could arise if further education and training is necessary. For each application a detailed calculation is needed, which considers the special application and requirements. Further investigations are necessary to decide if the investment is advisable or not, e.g. considering savings because of reduced waste and higher potencies of medicines, vaccines and food.

The project “sensor network and Raspberry Pi in humanitarian logistics” is one first project, which can be expanded to different applications. The test environment is one first example in which almost each component could be substituted by another. Sources of energy and power could be replaced by solar energy or other kinds of power sources, the alarm system could be replaced from a light system e.g. to a sound system, the personnel requirements could be adopted to the educational level available for each application (and it could be changed by special trainings for the staff or at universities), and the overall costs change with each replacement mentioned before. Even the single-board computer can be substituted, e.g. by another type such as Banana Pi, and the components of the sensor network could be replaced, as well. The first results from the test environment indicate that further research activities are reasonable to enhance logistics performance in cold chains for food and medicines in Sub-Saharan Africa.

“Current efforts to develop telecommunications infrastructure and information systems should enable African countries to mitigate capacity difficulties, and improve the efficiency of humanitarian supply networks in Africa [24, p. 163].” This paper contributes to the needed efforts and developments.

5. Conclusion and further research questions

One central objective mentioned above was to identify a fast and low cost temperature control system for humanitarian logistics in Sub-Saharan Africa, which is easy to implement, to use and to maintain and which works effectively. The system should meet the special challenges in and for Sub-Saharan Africa and should not exceed overall costs of US$ 350. This objective meets the aims and goals of humanitarian logistics and humanitarian aid, given and explained above. The visibility and transparency within the supply of medicines, vaccines and food – in the test-environment with a focus on temperature and humidity – have positive impacts on the quality of the products and therewith a positive impact on the health of the population in Sub-Saharan Africa. The first test-results can be summarized as positive trends, but several questions and research questions are still open and not answered.

Regarding the costs it can be stated that building a sensor network with a Raspberry Pi is relatively cost-efficient (in the test environment US$ 320 for one single solution). The overall costs of the whole sensor network vary in dependence of the country, the vendor, the type of system and its components, the shipping costs, and other factors. Costs are still one open question – a question of high priority for Sub-Saharan Africa.

Other open questions concern the education of personnel and IT-experts, e.g. open access learning environments for African students and other locals could be build up. Furthermore, open research questions concern the integration of supply chain visibility, power requirements, access to the internet and other technic-oriented questions. Alternative systems to the single-board computers are cheap notebooks, tablet PCs and mobile phones. With view on effectiveness and efficiency one research project could compare the Raspberry Pi with other single-board computers and alternative systems with sensor networks for humanitarian logistics in Sub-Saharan Africa.

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